Could the Electrostatic Force Play a Role in Holding the Atomic Nucleus Together?

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Abstract

An unheralded property of the electrostatic force is that as the distance between charges approaches zero the force increases exponentially without bound. Applied to the nucleus, if a positive fractional charge in one nucleon can get close enough to a negative fractional charge in a neighboring nucleon, the attractive force between them can overcome the repulsive force among protons. An effective distance of about 5% of the radius of a nucleon corresponds to an attractive force of -25 kN, which is consistent with the nuclear force as previously measured. As positive and negative fractional charges occur in both protons and neutrons, this charge-based attraction can potentially occur in a manner that is independent of the net charge of each nucleon. This form of electrostatic bonding may therefore be a significant factor in the nuclear force and may shed light upon the structure of the nucleons and the atomic nucleus.

Introduction

The atomic nucleus is held together by the nuclear force, a strong, short range, charge independent force that can overcome the electrostatic repulsion of the protons according to Coulomb's law. Understanding the nuclear force has been a challenge for eight decades [1].

The both the electric force and gravity have been universally dismissed as playing a role in holding the atomic nucleus together. For example, in Hans A Bethe's 1953 article “What Holds the Nucleus Together?” [2], the subtitle reads: “Electrical forces bind the electron to the atom, but they cause the nuclear particles to fly apart. The powerful cohesion of protons and neutrons must be explained by a wholly different phenomenon.” Within the article, Bethe speculated "even if the sign [of some charges] were changed so that they attracted one another, the electric force of attraction would be too small by a factor of 40 to account for the binding energy with which protons are held together in the nucleus."

Years later, opposite charges were found. The nucleons were probed and found to each contain three point-like electrostatic charges. Each proton has two charges of $+^2/_3$ e and one charge of $-^1/_3$ e, for a total charge of +1e. Each neutron has one charge of $+^2/_3$ e and two charges of $-^1/_3$ e, for a total charge of 0 [4].

In 2004, in a brief review of the history of physics in [4], Frank Wilczek recounted that "the known forces, gravity and electromagnetism, were insufficient to bind protons and neutrons tightly together into objects as small as the observed nuclei. Physicists were confronted with a new force, the most powerful in Nature." This review included a discussion of these fractional charges but did not question the dismissal of the electrical force as possibly having a role in holding the nucleus together.

The new force was called the nucleon-nucleon force, or just nuclear force. According to [1-3] the nuclear force is a short range force that binds together protons and neutrons into atomic nuclei. Characteristics of the force include charge independence, meaning that it applies to proton-proton, proton-neutron and neutron-neutron interactions. It is sensitive to spin alignment. It has a maximum attractive force of about 25,000 N at a distance of about 1 fm and becomes strongly repulsive at shorter distances. It is strong enough to overcome the collective electrostatic repulsion of the protons within the same nucleus, and that it is of such short range that at distances greater than about 2 fm only the long-range electrostatic force remains significant.

<u>Electrical Bonding of Fractional Charges</u>

In reviewing how the atomic nucleus is held together, I did not find any mention of a mathematical property that inverse square law forces have at extremely small distances, and which could potentially play a role in this nuclear force. Therefore, it is the purpose of this paper to reconsider the rejection of inverse square law forces as playing a role in holding the nucleus together.

The electrostatic force operates according to Coulomb's law, which describes the force between two charges at distance r,

$$F = k\,\frac{q_1 q_2}{r^2} \qquad where\ \ k = 8.98755 \times 10^9\,\frac{Nm^2}{C^2} \tag{1}$$

When the distance r approaches zero, equation (1) predicts that force increases exponentially without bound. In other words,

$$\lim_{r \to 0}\ k\,\frac{q_1 q_2}{r^2} = \infty \tag{2}$$

The meaning of distance r approaching zero can be easily misunderstood. In our macroscopic world, zero distance does not occur in a way that is meaningful to the inverse square law forces. When physical objects are said to touch they are actually responding to forces that hold them apart by at least atomic distances. The obstructions are the electron clouds that give atoms their volume.

However, in the femtometer-scale world of protons and neutrons (the nucleons of an atomic nucleus), zero distance has no such obstructions. The atomic nucleus is a tiny speck deep inside that cloud of electrons, smaller than one ten-thousandth the size of the atom. When a graph of the electrostatic force extends down to this unobstructed zero distance, at some point it takes a sudden turn like a bent knee, where the line gradually transitions from more predominately following a horizontal asymptote to more predominately following a vertical asymptote (Fig. 1).

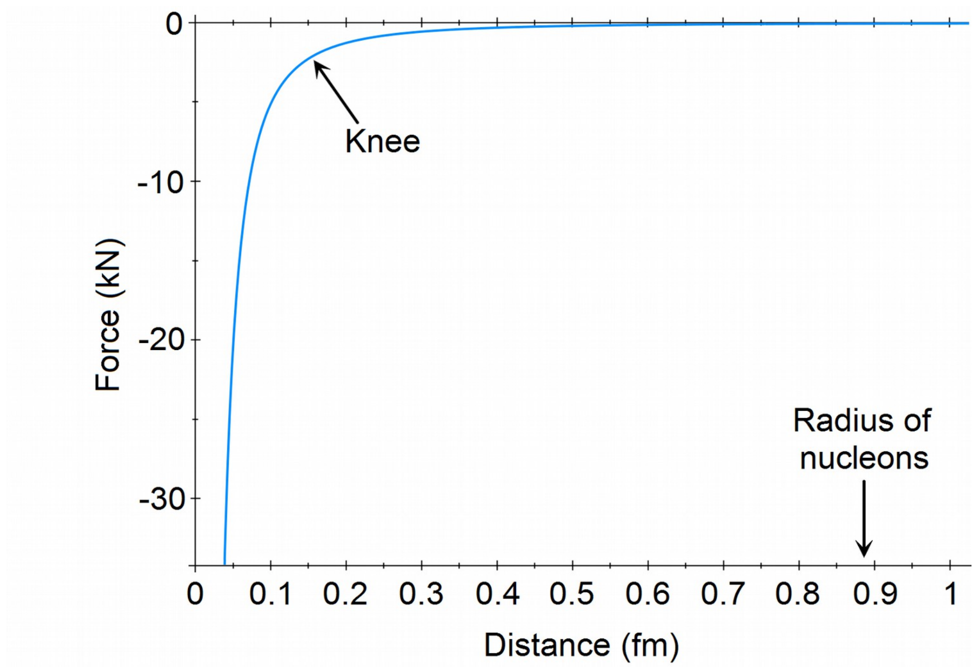

Fig. 1. *The electrostatic binding force between +2/3 e charge in one nucleon and -1/3 e charge in a neighboring nucleon grows dramatically as the effective distance between the charges is reduced, with a "knee" in the curve occurring at about 0.15 fm.*

The point of the knee could be considered to be the point of maximum curvature. However, it is not necessary to compute its exact position because nothing magical happens precisely at this point. The significance of the knee is a gradual transition from the familiar force that is predominately following its horizontal asymptote to an unfamiliar force that is predominately following its vertical asymptote.

The effective distance at which the knee occurs depends on the strength of the charges in the numerators of equations (1) and (2). For the opposing fractional charges found in nucleons, the point of the knee appears to be around 0.15 fm.

The radius of a nucleon is about 0.8 fm. This means the knee falls between shorter distances possibly seen where neighboring nucleons are bound to each other (perhaps touching) and greater distances seen where protons repel each other because of their net positive charges.

Mathematically, the knee divides the electrostatic force into two radically different kinds of behaviors. All of our experience where we recognize the electrostatic force takes place at distances greater than the point of the knee. Usually, it is at much greater distances. Even the mutual repulsion of protons in the same nucleus takes place in the familiar zone of distances greater than the point of the knee.

At distances less than the point of the knee, according to the equations (1) and (2), the electrostatic force is capable of any force needed to hold the nucleus together. The effective distance that would generate the needed force can be determined by solving the equation (1) for the distance r:

$$r = \sqrt{k \frac{q_1 q_2}{F}} \tag{3}$$

Using the 25,000 N binding force as a goal (matching the maximum attraction of the traditional nuclear force), and using the known +2/3 e and -1/3 e fractional charges that are available, and assuming favorable spin alignment (but otherwise ignoring its effect), the effective distance r comes out to be 0.045 fm.

Charge Independence

According to [1-3], another property of the nucleon-nucleon force is charge independence, meaning that it affects neutrons and protons alike even though protons have a charge and neutrons do not. The traditional nucleon-nucleon interaction has been found in proton-neutron (P-N), neutron-neutron (N-N) and proton-proton (P-P) bindings. In proton-proton bindings the force matches after compensating for the electrostatic repulsion of the protons.

When viewing the protons and neutrons as having whole number positive charge and no charge, respectively, the nuclear force does seem to be independent of charge. In such a simplified view of net charges of nucleons, it seems that the only electrostatic forces in question are repulsive, that there has to be some entirely different kind of force that is overpowering the electrostatic force to hold the nucleus together, and that this entirely different kind of force does not care whether the nucleons have an electrostatic charge or not [1].

However, looking closer into the nucleons (as shown in Fig. 2) we see that both protons and neutrons have $+{}^{2}/_{3}$ e and $-{}^{1}/_{3}$ e charges in them [4]. We see that while each neutron has no net charge, it is not electrostatically neutral at close distances. We see opposite charges available for electrostatic forces in the attractive direction, and we see that the neutron is not an idle player but has fractional charges that should be considered capable of playing an important role.

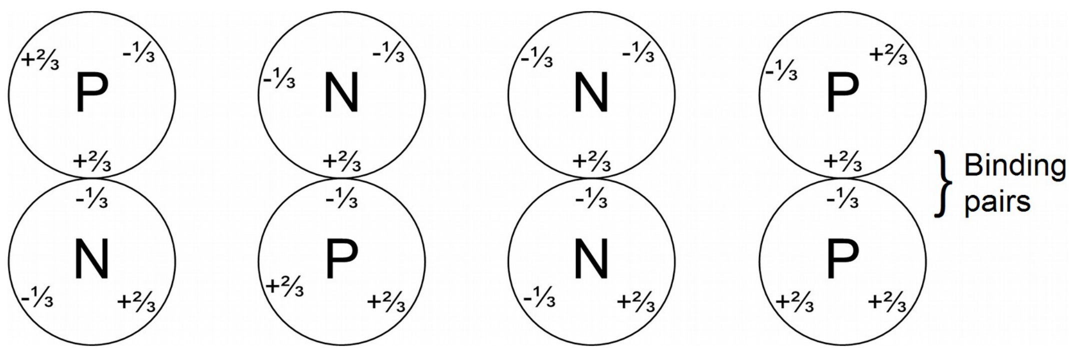

Fig. 2. Schematic diagram showing that there are four distinct combinations of two nucleons experiencing electrostatic binding between fractional charges.

Because every binding pair will include both a $+{}^{2}/_{3}$ e charge and a $-{}^{1}/_{3}$ e charge, every binding pair has a net charge of $+{}^{1}/_{3}$ e. This net $+{}^{1}/_{3}$ e charge that is leftover from a binding will repel unbound $+{}^{2}/_{3}$ e charges, if any, as well as other net $+{}^{1}/_{3}$ e charges that are leftover from other bindings. These latter two types of repulsion should be expected to occur at distances significantly farther apart than the bindings, meaning distances where the force is nearer to its horizontal asymptote and thus is much smaller than the force of the bindings themselves.

(This analysis is based on the axiomatic acceptance of protons and neutrons being composed of

$+^{2}/_{3}$ e and $-^{1}/_{3}$ e charges. As this was discovered by deep inelastic scattering of bound protons and neutrons [4], and a net $+^{1}/_{3}$ e charge was not observed, perhaps there is a chance that some of the observed fractional charges are actually net charges of unknown types of electrostatically bound pairs.)

Table 1 summarizes and compares the traditional nuclear force with electrostatic binding of fractional charges.

The question of gravity

Gravity is also an inverse-square law force that has been considered and dismissed by [1] and others as playing any significant role in holding the nucleus together. The force equation for gravity is:

$$F = G\frac{M_1 M_2}{r^2} \qquad where\ G = 6.67384 \times 10^{-11} \frac{m^3}{kg\, s^2} \tag{4}$$

It takes the same form as equation (1), Coulomb's law, so it is easily seen that the force of gravity may also increase exponentially without bound as the distance r approaches zero. All that is required is two masses that are compact enough to get close enough and for the law of gravity to still hold at those distances. For each pair of masses, the knee in the curve will occur at a different distance depending on the size of the product of the masses.

For gravity to have this effect, the point masses must not merely be the mathematical center of something diffuse. They would have to have actual sizes on the order of the effective distance, as diffuse masses much larger than the effective distance would introduce internal distances exceeding the effective distance.

Using the entire mass of a proton (to put an upper limit distance required) and treating it as if it were a point mass, obtaining a gravitational force of -25 kN bwtween two such point masses would require an effective distance of no more than 9 x 10^{-35} meters. Thus, considering that a much smaller fraction of the mass of a proton would be more realistic, for gravitation to play a significant role, the supposed point masses would have to be on the order of a Planck length (1.6 x 10^{-35}). This is quite unlikely.

Conclusion

An unheralded property of the inverse square law forces is that as distance approaches zero the force makes a turn and increases exponentially without bound. When the electrostatic force is considered with the fractional charges and distances found in the atomic nucleus, it makes this turn at about 0.15 fm (17% of the radius of a nucleon). If opposite fractional charges in neighboring nucleons can get within an effective distance of 0.045 fm, the predicted attractive force matches the maximum force of the traditional nuclear force of -25 kN. Thus, ironically, the electrostatic force may play a significant role in holding the nucleus together. Again ironically, such charged based bonds can mimic the charge independence of the nuclear force, because the necessary positive and negative fractional charges are found in both protons and neutrons.

References

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[3] Robert E. Marshak, The Nuclear Force, *Scientific American*, 202(3) (1960)

[4] Frank Wilczek, Asymptotic Freedom: From Paradox to Paradigm, *Proceedings of the National Academy of Science*, 102, pp. 8403- 8413; available at: hep-ph/0502113

Table 1. Comparison of traditional nucleon-nucleon force to electrostatic bonding of fractional charges.

Characteristic	**Traditional Nuclear Force**	**Electrostatic Bonding of Fractional Charges**
Description	A phenomenon entirely different from any known force; a short-range force; not an inverse-square law force.	An unappreciated property of the electrostatic force; an inverse square law force has a vertical asymptote too.
Strength	25,000 N	Can be whatever is needed, including 25,000 N
Distance corresponding to 25,000 N	About 1 fm	0.045285 fm (between fractional charges).
When closer than maximum force distance	Becomes extremely repulsive. Is given credit for incompressibility of the nucleons.	Charge to charge distance can't be compressed. Something else must be making the nucleons resilient so this is not really part of the nucleon-nucleon force.
When farther than maximum force distance	Measured force drops off rapidly so that by about 2 fm it becomes insignificant.	Computed force drops off rapidly so that by 1 fm (between fractional charges) it becomes insignificant.
Charge independence	Applies to P-P, P-N and N-N interactions because it seems to be charge-agnostic.	Applies to P-P, P-N and N-N interactions because in every one of those cases it is possible to find the necessary +2/3 e and -1/3 e fractional charges, even in neutrons.
Spin	Is sensitive to spin alignment.	Is sensitive to spin alignment.
Dual action of one force	Traditional nuclear force is deemed responsible for both attraction farther than about 0.8 fm and more intense repulsion nearer than about 0.8 fm, center to center.	The electrostatic force is found to be mathematically capable of both net repulsion farther than about 0.15 fm and more intense attraction nearer than about 0.15 fm.
Effect of dual action	The same traditional nuclear force is deemed responsible for both holding the nucleus together and giving the nucleus its volume.	The same electrostatic force is responsible for both making the nucleus want to fly apart and for bonding neighboring nucleons together.